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## DRIVE SYSTEM

The present invention relates to a drive system and in particular, but not exclusively, to a drive system for a bicycle. The drive system is also applicable to other human-powered vehicles and mechanisms. The invention also relates to a bicycle having a drive system.

- 5 The drive system used by conventional bicycles consists of a pair of rotating pedal cranks connected by a chain and sprockets to the rear wheel. This system has certain disadvantages. In particular, the tangential force the cyclist is able to exert on the pedals varies considerably according to the positions of the pedal cranks and is at a maximum only when the pedal cranks are approximately horizontal. This limits the efficiency and/or
- 10 maximum power output of the cyclist.

DE 4404831 A describes a drive system including a drive link that is coupled by bearings to a crank and a tie rod. Drive is transmitted from the drive link through the crank to the wheels of a bicycle.

- 15 WO 96/22911 describes a drive mechanism for a bicycle, in which the pedals are attached to racks mounted for reciprocating movement.

It is an object of the present invention to provide a drive system that mitigates the aforementioned disadvantage. A further object of the present invention is to provide a bicycle having a drive system that enables the cyclist to provide a greater power output and/or to cycle more efficiently.

- 20 According to the present invention there is provided a drive system suitable for use in a bicycle, said drive system including a manually-operable means and a drive train connected to the manually-operable means for transferring drive from the manually-operable means to at least one of the bicycle wheels, wherein the manually-operable means is mounted for substantially rectilinear reciprocating movement on a lever system that includes a first lever
- 25 having a first end connected to a first pivot and a second end that is rotatable about the first fixed pivot, a second lever having a first end that is pivotably connected to the second end of the first lever and a second end to which the manually-operable means is attached, and a tie rod having a first end that is pivotably connected to a second pivot and a second end that is pivotably connected to the second lever between the first and second ends thereof;
- 30 characterised in that the first lever is constructed and arranged for limited reciprocating rotation of the second end about the first pivot.

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Although the drive system is suitable for use in a bicycle, it may also be used for driving other vehicles or mechanisms. It is not intended that the present invention is limited to drive systems for bicycles. The lever system produces the substantially rectilinear reciprocating movement of the manually-operable means, and is very efficient in operation.

- 5 The manually-operable means is preferably a pedal or a pair of pedals, although it may alternatively be a handle. Mounting the manually-operable means for substantially rectilinear reciprocating movement allows a very efficient input of energy into the drive system from the user, avoiding the inefficiencies of traditional rotating crank systems. A bicycle equipped with the drive system can therefore be ridden more quickly and/or with  
10 less effort.

Advantageously, the drive system includes two lever systems that are interconnected for opposed reciprocating movement, each lever system including a manually-operable means. This allows both feet, or both hands, to be used to drive the system with alternating strokes.

- The drive system may include a hydraulic drive pump that is connected to a third pivot and  
15 to the first lever between the first and second ends thereof, for actuation by pivoting movement of the first lever. The system may also include an adjuster device for adjusting the position of the third pivot relative to the first pivot, to adjust the stroke length of the cylinder. Advantageously, the adjuster device is a hydraulic adjuster. The hydraulic drive pump may be connected through a hydraulic circuit to a hydraulic motor.

- 20 The use of a hydraulic drive train allows drive to be transferred efficiently to the wheels, while adjusting stroke length of the hydraulic pump provides a simple method of adjusting the gearing effect of the drive system. If a hydraulic adjuster is used, an automatic or semi-automatic gearing system can be provided. While a hydraulic drive train is preferred, the drive train may alternatively be entirely mechanical.

- 25 In an alternative preferred form of the invention, the manually-operable means is attached to a shaft that is mounted for axial reciprocating movement. Advantageously, the system includes a pair of shafts mounted substantially parallel to one another for axial reciprocating movement, each said shaft having a manually-operable means attached thereto. The shafts are preferably interconnected for opposed reciprocating movement.

- 30 This system also produces the substantially rectilinear reciprocating movement of the manually-operable means, and is very efficient in operation. The use of two parallel shafts

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that are interconnected for opposed reciprocating movement allows both feet, or both hands, to be used to drive the system with alternating strokes.

Advantageously, the shafts are drivingly connected to a sub-shaft that is mounted for axial reciprocating movement, and are preferably mounted substantially perpendicular to the sub-shaft. The sub-shaft may be connected to a hydraulic drive pump, which may be connected through a hydraulic circuit to a hydraulic motor. The use of a hydraulic drive train allows drive to be transferred efficiently to the wheels.

Advantageously, the hydraulic drive motor is a variable capacity motor, which allows the gearing effect of the drive system to be adjusted.

- 10 Advantageously, the drive system includes a plurality of hydraulic motors and means for connecting the motors into the hydraulic circuit individually, in series or in parallel, to adjust the gearing effect of the drive system.

According to another aspect of the present invention there is provided a bicycle having a drive system as described in the preceding paragraphs.

- 15 The bicycle may includes a hydraulic drive train including at least one hydraulic motor for driving the rear wheel, the front wheel or both wheels of the bicycle. The bicycle may include a plurality of hydraulic motors that can be connected into the hydraulic circuit individually, in series or in parallel to adjust the gearing effect of the drive system.

Embodiments of the invention will now be described, by way of example, with reference to

- 20 the accompanying drawings, in which:

I Fig. 1 is side view of a first embodiment of the drive system;

Fig. 2 is a side view of a bicycle having a drive system as shown in Fig. 1;

Fig. 3 is a hydraulic circuit diagram of a hydraulic drive train for use with the drive system;

II Fig. 4 is an isometric view of a second embodiment of the drive system;

- 25 Fig. 5 is a front view of the second drive system;

Fig. 6 is a side view of the second drive system, and

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such a way that the fluid in the drive system operates the adjuster so providing automatic adjustment of the gear ratios. Both sides may be connected together to ensure that the pedals move in opposite directions.

The hydraulic circuit may be arranged as shown in the diagram included here for clarity only. Fluid is drawn from the reservoir 15 through a one way valve 18 to the hydraulic cylinder 10 and pumped under pressure through another one way valve 19 to the control system 16 and so through motors 17 as required then returning to the reservoir. A small amount of fluid is passed into a second control system 20 to actuate the adjuster 12.

In alternative arrangements, the hydraulic components may be replaced by a gear, shaft or chain drive. In these arrangements provision will be made for relative movement of the pivots to provide a range of gear ratios.

The constituent parts are so arranged that the movement of the pedal and output is in relation to the force that can be exerted on the pedal. There is no point in the cycle that a full force cannot be output by the system. By aligning the direction of pedal movement with the input force the system makes more efficient use of the work energy available.

Various modifications of this drive system are possible. For example, the drive cylinder may be connected to the second arm instead of the first arm; the lever to which the pedal is attached may be curved rather than straight; and the whole mechanism may be oriented differently, for example when it is advantageous for the person operating the drive system to adopt a reclined position.

An alternative drive system is shown in Figs. 4 to 7. In this system, the pedals 30 are attached to the lower ends of two parallel pedal shafts 32, which are mounted for axial movement in a housing 34 and are connected to a hydraulic drive piston 36 through a pair of transfer gears 38 and a piston shaft 40. The housing is shown in Fig. 6 but is omitted from the other figures for clarity.

Each pedal shaft 32 is provided on one face with a gear rack 42: in the embodiment shown in the drawings the rack is provided on the rear face of the left-hand pedal shaft and on the front face of the right-hand pedal shaft.

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The transfer gears 38 are mounted in the housing 34 with their axes perpendicular to the axes of the pedal shafts 32. Each transfer gear includes a large radius gear 44 at its outer end, which engages the rack 42 on the associated pedal shaft, and a smaller radius gear 46 at its inner end, which engages an associated gear rack 48 on the upper side of the piston shaft 40.

The piston shaft 40 is mounted for axial movement in the housing 34 and is connected at one end to the hydraulic drive piston 36, which with a cylinder 50 forms a hydraulic drive pump 52. The drive pump 52 is connected through a hydraulic circuit to a drive motor. The drive motor may be a variable displacement motor, to provide a gearing effect.

- 10 To operate the drive system, the pedals 30 are pushed upwards and downwards by the rider, causing the pedal shafts 32 to reciprocate. This reciprocating movement is transferred to the piston shaft 40 by the transfer gears 38, which also increase the force and reduce the amplitude of the movement. This drives the hydraulic pump 52, which in turn drives the motor.
- 15 A suitable variable displacement motor 54 is shown in Fig. 8. The motor 54 includes a rotor 56 that is hexagonal in cross-section and has six cylinders 57 around its circumference, in each of which is mounted a piston 58. The rotor 56 is mounted for rotation on a fixed, non-rotatable shaft 60 having a shaft axis 61. The six pistons 58 slidably engage the inner hexagonal walls 62 of an outer housing 64, which is mounted on
- 20 a mounting plate (not shown) for rotation about a housing axis 65 with the rotor 56, and is drivingly connected to one or both of the bicycle wheels.

Sealing walls 66 are provided on the shaft 60, which divide the annular gap 67 between the shaft and the rotor 56 into two halves. Oil is fed to and drained from each half of this gap through an oil inlet opening 68 and an oil outlet opening 70 in the shaft 60. Vents 72 in the

25 rotor 56 extend between the gap 67 and the cylinders 57, allowing oil to drive the pistons 58.

The shaft 60 is mounted on an eccentric 73 having an axis of rotation 74, which can be rotated to vary the separation between the shaft axis 61 and the housing axis 65. This

allows the swept volume of the pump 54 to be varied, thereby adjusting the torque and the gearing ratio. Rotation of the eccentric may be limited by stops (not shown).

In operation, oil is supplied under pressure through the inlet opening 68 into the gap 67 between the shaft 60 and the rotor 56, and passes through the vents 72 into the three cylinders 57 located on the inlet side of the gap 67, so driving the pistons 58 in those cylinders outwards. At the same time, oil is exhausted from the three cylinders on the outlet side of the gap 67 and escapes through the outlet opening 70. The unbalanced force generated by the pistons creates a turning moment on the rotor, owing to the separation between the shaft axis 61 and the housing axis 65. The rotor 56 and the housing 64 therefore rotate about the shaft 60, driving the wheel or wheels of the bicycle.

By rotating the eccentric 73, the separation between the shaft axis 61 and the housing axis 65 can be varied to adjust the torque and gearing ratio. Rotation of the eccentric 73 may be controlled manually or automatically (for example, mechanically or hydraulically) to provide a self-regulating drive system.

Various modifications of the drive system are possible. For example, in the embodiment shown in the drawings, the transfer gears 38 are arranged to engage gear racks on opposite sides of the two pedal shafts 32, so that the pedals 30 move in opposite directions. Alternatively they can be arranged to engage gear racks on the same side of the two pedal shafts 32, and on opposite sides of the pump shaft 40, to produce the same effect. It is also possible to mount both transfer gears on a single shaft, which has its axis situated diagonally with respect to the gear rack on the pump shaft.

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